The influence of involuntary facial movements on craniofacial anthropometry: A survey using a three-dimensional photographic system

Abstract

Purpose

In the modern anthropometry of complex structures, such as the face, different technical approaches for three-dimensional (3D) data acquisition have become increasingly more common. Results of meticulous evaluations have demonstrated a high level of precision and accuracy under both ideal and clinical circumstances. However, the question remains regarding which level of accuracy is adequate to meet clinical needs. Aside from the measuring technique itself, potential sources of error need to be identified and addressed. Involuntary facial movements in the subjects potentially influence clinical reliability.

Materials and Methods

The 3dMDface^{TM} system was used in a clinical setting to investigate the influence of involuntary facial movements. Other factors of influence were systematically excluded. The mean technical error of the system (0.09 mm) was investigated in a previous study and taken into account for interpretation of the data.

Results

The handling of the system was unproblematic for both data acquisition and data analysis. Including technical error and the influence of involuntary facial movements, the mean global error was 0.41 mm, with a range from 0.00 mm to 3.30 mm. Taking into account the technical error of the system known from the previous study, involuntary facial movements account for a mean error of 0.32 mm.

Conclusions

This range of involuntary facial movements clearly exceeds the known technical error of the utilized 3D photographic system. Given this finding, future

research should shift its focus from the analysis of the technical aspects of such systems to other influencing factors.

Keywords

maxillofacial surgery; craniofacial surgery; plastic surgery; comparative study; photogrammetric imaging; anthropometry

INTRODUCTION

Anthropometry is the biological science of measuring the human body and its characteristics.[1] In cranio-maxillofacial and plastic surgery, anthropometry is especially challenging due to the complex three-dimensional (3D) structures of the face, which inhibit assessment with simple measurements. The development of computer tomography (CT) solved the difficulties associated with measuring underlying bony structures. Today CT is commonly used for evaluation of bony structures[2-6] and is also used for soft tissue evaluation in select situations.[4, 7, 8] However, a radiation-free, objective, accurate, and reliable system for quantifying the soft tissues of the face in dimension and colour is still needed.

Direct measurements and two-dimensional photography are state of the art for craniofacial anthropometry,[9] although their limitations are well-known.[1, 10] The interest in overcoming the limitations of these techniques led to the development of numerous 3D scanning devices. A large body of literature supports the high level of technical accuracy and clinical usability provided by these systems.[11-15] Obviously, before any of these new techniques are applied clinically, it is crucial to evaluate their reliability.[16, 17] Beyond these technical aspects, the proper and reliable identification of landmarks is also crucial.[18, 19]

However, factors beyond the technical precision and reliability of landmark identifications may have been underestimated to date. The face undergoes constant changes due to mimic activity. Even if no explicit facial expression is intended, small changes in mimics are expected. Those changes might influence all types of 3D evaluation protocols. To our knowledge, no study has attempted to quantify changes in 3D clinical landmark positions due to involuntary facial movements of the subject. That is, the question regarding the differences in two 3D photographs taken within a short time period of time (e.g., seconds or minutes) of one subject's resting face has not been answered yet.

We define the so-called "involuntary facial movements" as mimic activity that is not intended by the subject and outside of his or her awareness. Since it is always present in any subject it has to be accounted for when analysis of facial changes (e.g. preoperative vs. postoperative facial appearance) is performed.

AIM OF THE STUDY

The aim of this study was to (1) evaluate the extent of involuntary facial movements in comparison to the known precision (repeatability and reproducibility) and accuracy of the 3dMDface™ system[20] and (2) clinically judge whether this factor influenced the reliability of craniofacial soft tissue evaluation. The technical parameters of the system, such as accuracy, bias, and precision, were not part of this study.[16, 21]

MATERIALS AND METHODS

Model

To evaluate the influence of involuntary facial movements of a compliant clinical subject, the faces of two of the authors were prelabeled with 61 standard surface landmarks (Figures 1 and 2). The labels were positioned to cover all facial regions, with an emphasis on the oral-nasal region. There was no obvious craniofacial dysmorphology or impairment of muscle function.

Data acquisition

The data were acquired under clinical lighting using a 3dMDface™ system (3dMD Inc., Atlanta, GA, USA). The system is based on a combination of stereophotogrammetry and structured light. Further, it is connected to a personal desktop computer where the captured dataset is saved and calculated into a 3D Virtual Reality Modeling Language (VRML) file (45,000 to 65,000 polygons) that is ready for evaluation. Data acquisition was performed in natural head posture (NHP), with the Frankfurt horizontal line parallel to the floor.

Both subjects' faces were captured 20 times consecutively. 3D representations were built by the capturing system (see Figures 1 and 2). Interposed between each data acquisition was a 10-minute break with normal mimic activity, including talking, laughing, drinking, and eating. Immediately prior to image capturing, the subjects were instructed to swallow hard and to keep their jaws in a relaxed position. There was no manipulation of the 3D photograph system during the break.

Data processing

Additional data processing was performed on a standard desktop computer using the 3dMD-Patient-Software (3dMD Inc., Atlanta, GA, USA) provided with the capture device. The labels were digitized on the surface of the 3D model, and the x-, y- and z-coordinates of these markings were exported to an Excel 2003 (Microsoft Corporation, Redmond, WA, USA) file for further calculations. A zoom tool was available for use for magnification on the screen.

On the one hand, a superimposition of the individual datasets with translation and rotation only was not possible due to the expected morphologic changes in the surfaces resulting from involuntary facial movements. On the other hand, any morphing algorithm would unacceptably influence the results. For this reason, the classical target registration error could not be evaluated.[17, 22]

Instead, the data were analyzed by examining calliper distances calculated from one landmark to another (a total of 1387 distances per dataset) using the following formula: $\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$. This formula yield the direct 3D distance between two coordinates. The first 3D dataset served as the reference dataset. The null hypothesis was that the corresponding distances in all 19 datasets were identical.

The technical error of the 3D photo system was investigated in a previous study utilizing a phantom in the exact same photographic setting.[20] When checking the null hypothesis this known error of 0.09 mm was taken into account. The error resulting from involuntary facial movements was compared to the different technical error classes evaluated by the previous study (operator error and capture error).

Statistical tools

The acquired data were analyzed using descriptive statistics and parametric Student's t-tests. The tests were performed with SPSS 11.5 (SPSS Inc, Chicago, IL, USA). The significance level was preset at $p<0.05$.

RESULTS

For subject 1, the mean error of all distances and all datasets was 0.48 mm, with a range from 0.00 mm to 3.30 mm. The discrepancies between the reference dataset for subject 1 and the following 3D datasets are shown in Figure 3. As depicted, the minimums for each model were very close to 0 mm, whereas the maximums were as much as 3.30 mm.

For subject 2, the mean error of all distances and all datasets was 0.33 mm, with a range from 0.00 mm to 2.48 mm. The discrepancies between the reference dataset for subject 2 and the following 3D datasets are shown in Figure 4.

A comparative analysis combined with known technical error classes from a previous phantom study[20] is illustrated in Figure 5. The operator error (with and without zoom) reflects the error resulting from inaccuracies in marking the labels in the software. The capture error is resulting from the technical aspects of the photographic system itself. Figure 5 depicts the larger range of precision if involuntary facial movements are part of the evaluation as they are in the living subjects of this study. The error due to involuntary facial movements is far higher than all other error classes.

Some practical limitations of the utilized technology were observed during testing. First, it is difficult to capture data if hair compromises any of the camera's view of the area (compare hairline area in Figure 2). Second, wet skin presents challenges for the capturing system, as they often result in artefacts (compare eyelid region in Figure 6). Third, prominent areas can compromise the view of less prominent areas, resulting in poor 3D representation (compare submental and nostril region in Figure 6).

DISCUSSION

By definition, analyzing the facial soft tissues presents challenges from small movements due to different factors. Some, such as those arising from one's nutritional state, are a problem only over longer periods of time, although others, such as involuntary facial movements, occur from one moment to the next.

The results of the present study indicate that involuntary facial movements are a relevant factor in the anthropometry of the face. Despite using an exact protocol for adults, having compliant subjects, and performing data acquisition strictly in the natural head posture (which Kau et al.[23] were able to show was clinically reproducible), it was found that the negative influence of involuntary facial movements was still far greater than that of all other factors.

In comparison, the well-studied system error of 3D imaging techniques, which is within the same range in most modern systems, [16, 20, 24] is relatively negligible. As shown in Figure 5, the error in prelabeled living subjects is much higher than the technical error investigated in prelabeled casts. The differences can only be explained by involuntary facial movements, given that the rest of the setup was identical. The range of error (0.0 mm to 3.30 mm and 0.0 mm to 2.48 mm, respectively) is the primary concern arising from the results and is especially obvious in Figures 3 and 4, which show the overall error of each dataset compared to its reference dataset.

For hard tissue evaluation, 1 mm is the critical value to be achieved because higher precision is often technically not achievable during surgery.[25] For soft tissue evaluation, we considered 1.5 mm to be clinically acceptable, given that discrepancies in most facial soft tissue structures below 1.5 mm are not observable to the naked eye, even among experienced examiners. However, the level of inaccuracy observed in this study is far higher than 1.5 mm; therefore, involuntary facial movements need to be taken into account during any evaluation of soft tissues. Future research should focus on the identification of landmarks that are influenced by involuntary facial movements to a lesser extent and can safely be utilized for clinical evaluation of soft tissues of the face.

If in future clinical investigations high precision is needed especially for landmarks known to be influenced by <u>involuntary facial movements it might be useful to establish a baseline figure of involuntary facial movement for each individual subject to be investigated. Similar to the presented study landmarks in question could be evaluated by a number of repeated photographs and a baseline inaccuracy due to involuntary facial movements can be established and be taken into account during data interpretation.</u>

The difficulty associated with hair-covered areas is a concern for facial applications in patients with beards. Three-day beards are not a big issue but if hair gets longer 3D imaging can be impossible.

Hair also is a major concern for investigations of skull deformities. Partially, this challenge can be overcome by placing a tight hood over the subjects' hair. However, this introduces another factor of inaccuracy into the evaluation, which must be taken into account. It might be acceptable because the range of precision that is clinically necessary for the evaluation of skull deformities is lower than for facial evaluation, due to the hair coverage and other factors.

Wet skin areas occur mainly in the perioral region. This region is of special interest, especially in patients with a cleft palate. In adult patients, the problem of wet skin areas can easily be addressed if the examiner is aware of it. However, it remains a problem, especially in children with a cleft lip.

Prominent areas blocking out less prominent areas, such as the nose and the edges of an untreated cleft, must be avoided by meticulous positioning of both the cameras and the patient. Sometimes, it is impossible to get a good 3D representation of all of the important regions with one capture. Therefore, multiple captures are often necessary in difficult situations. We hope that some of these problems can also be addressed by technical innovations, such as the use of additional cameras as well as different wavelengths.

CONCLUSIONS

Unconscious mimics are a major concern in facial anthropometry. Rather than focusing on the technical aspects of the 3D imaging systems used, future researchers should focus on strategies that account for this mimic activity. Potential solutions include the definition of landmarks that are less influenced by mimics or a concept of overlapping multiple images in order to generate a “mean” dataset representing some type of mean mimic setting. As a last step, the entire concept should be transferred into 4D, which involves the 3D capturing not only of a still image, but also of a moving object.

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DISCLOSURE STATEMENT

As it pertains to the above article, the authors declare that they have no dual commitment and/or potential conflict of interest. The authors also declare no unlabeled and/or investigational use of any commercial product.

CAPTIONS

Figure 1. 3D representation of subject 1 (first author) as captured by the system

Figure 2. 3D representation of subject 2 (last author) as captured by the system. Poor and partially missing 3D representation at the hairline region due to the hair's compromising the data capture acquisition

Figure 3. Error through unconscious mimics in subject 1. (The blue line represents the mean differences between distances in the reference dataset 1 and dataset as numbered on the x-axis; the continuous lines represent the 95% confidence intervals; the dashed line represents the minimal differences (almost on the x-axis) and maximum differences)

Figure 4. Error through unconscious mimics in subject 2. (The blue line represents the mean differences between distances in the reference dataset 1 and dataset as numbered on the x-axis; the continuous lines represent the 95% confidence intervals; the dashed line represents the minimal differences (almost on the x-axis) and maximum differences)

Figure 5. Comparative analysis combined with known error classes (operator and capture error as reported by Luebbers et al.[20])

Figure 6: Poor 3D representation of the eyelids due to the wet surface's compromising the data capture acquisition and poor 3D representation of the submental and nostril region due to prominent areas' compromising the data capture acquisition of less prominent areas

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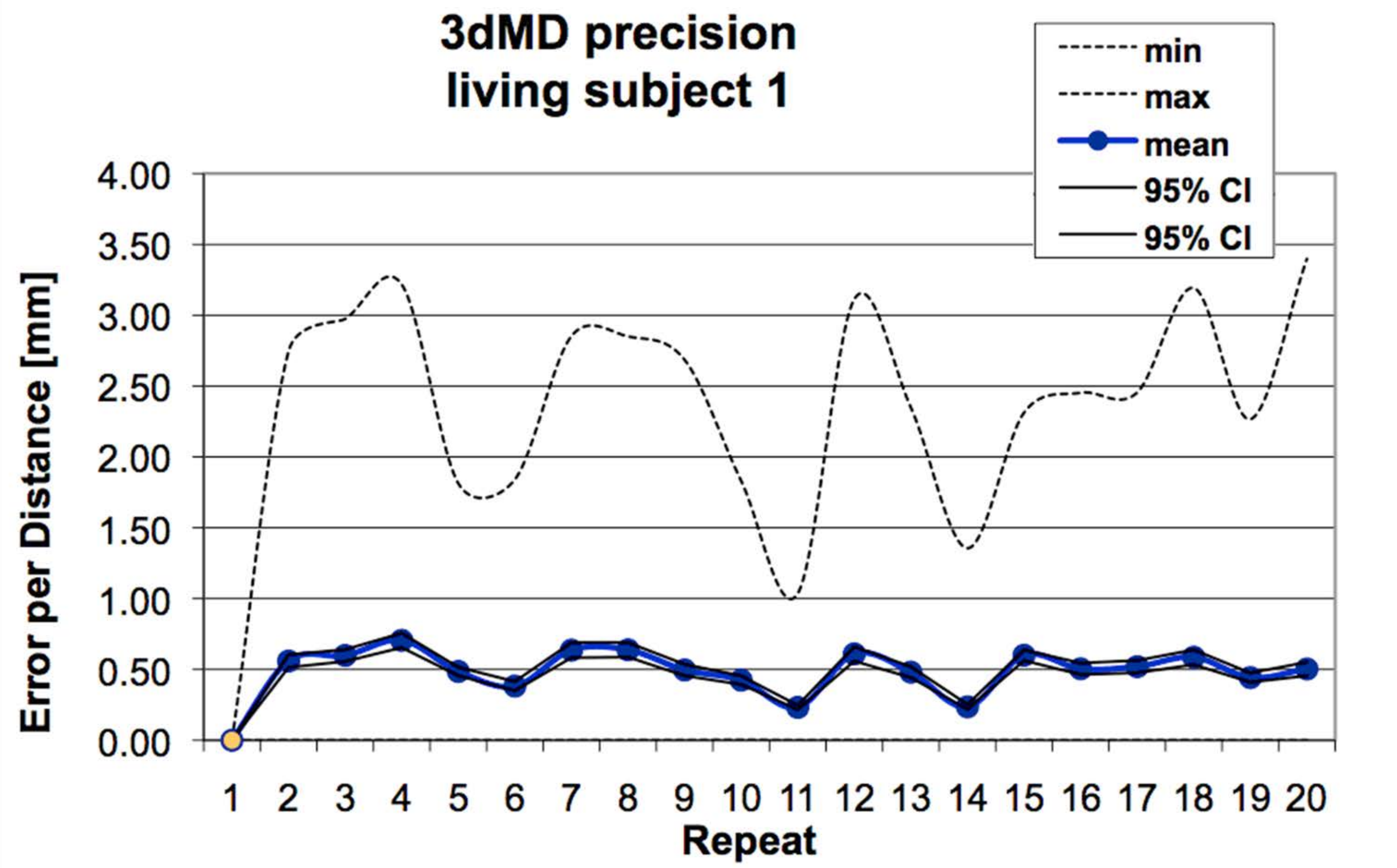
3dMD precision
living subject 1
min
max
mean
95% CI
95% CI
4.00
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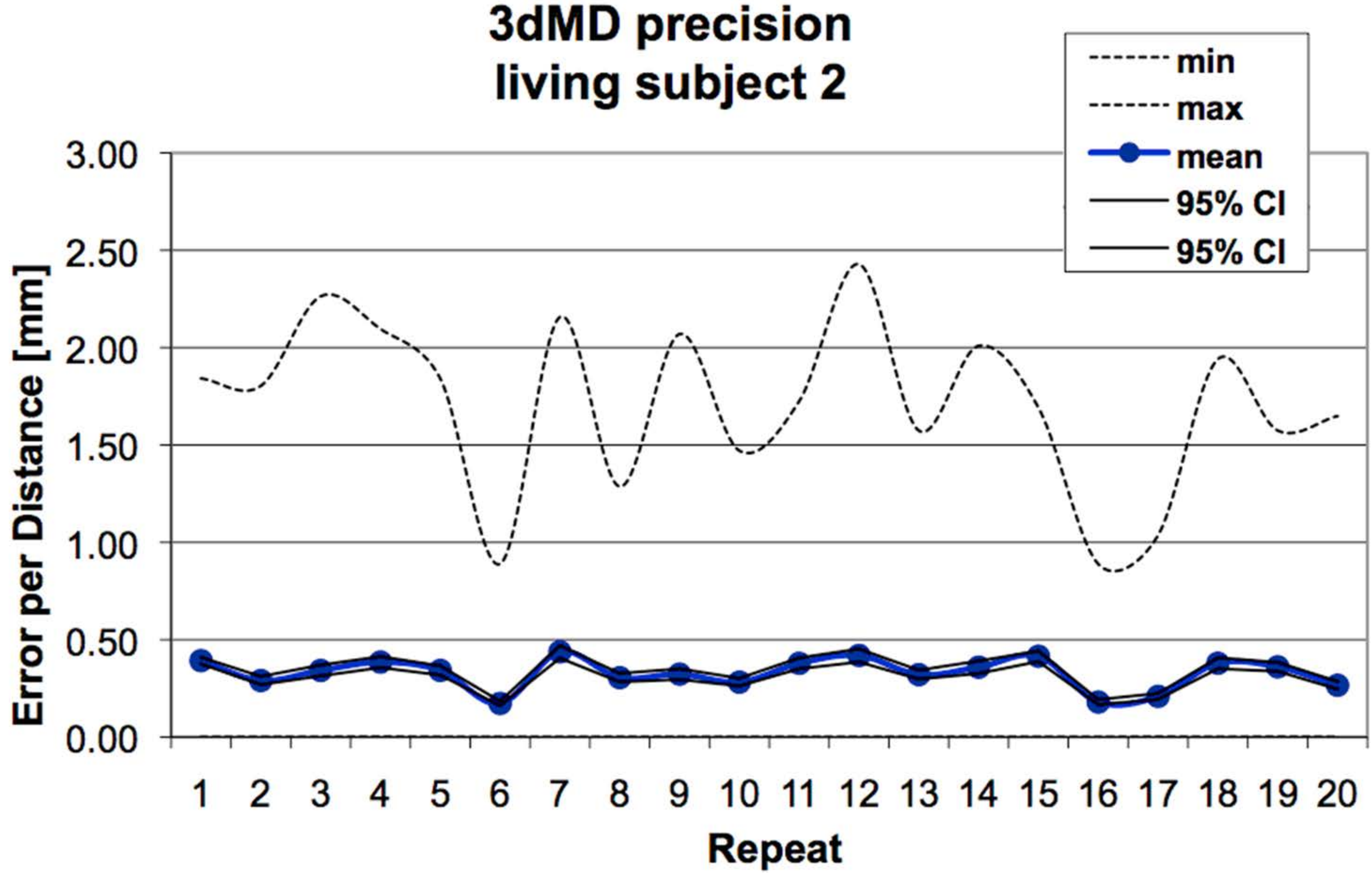
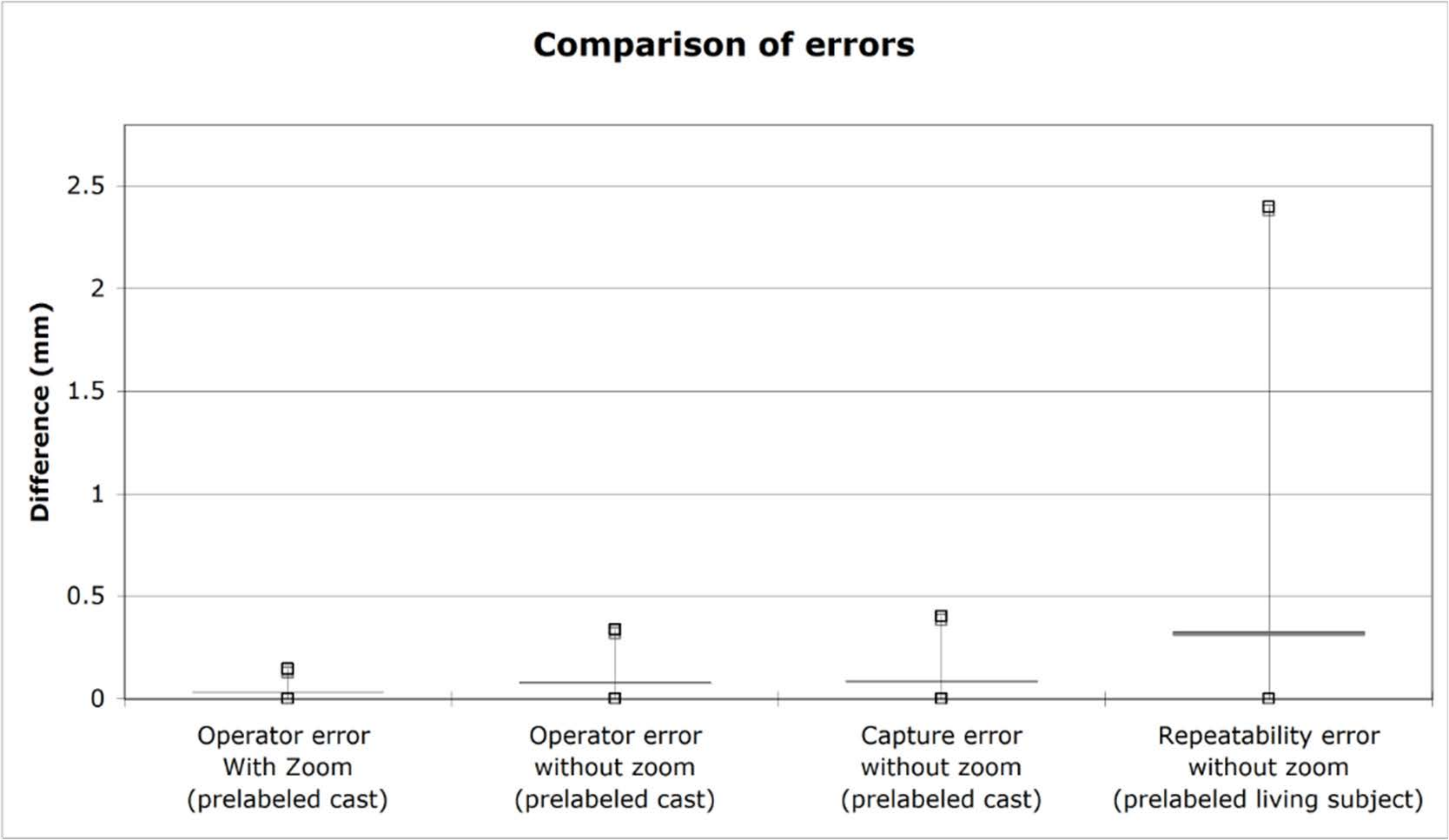
Error per Distance [mm]
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Repeat


3dMD precision
living subject 2
min
max
mean
95% CI
95% CI
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Error per Distance [mm]
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Repeat


Comparison of errors
Difference (mm)
2.5
2
1.5
1
0.5
0
Operator error With Zoom (prelabeled cast)
Operator error without zoom (prelabeled cast)
Capture error without zoom (prelabeled cast)
Repeatability error without zoom (prelabeled living subject)